Ocean Engineering Laboratory
University of California
Santa Barbara, California 93106-1080

Final Report: Navy Contract N00014-86-K-0866

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Introduction:

This contract was carried out during the period 10/1/86 to 9/30/89 with a no-cost extension until 4/30/91.

Work under this contract was reported in a series of technical reports and publications; as well as in public lectures and seminars. In addition, annual reports were submitted to the Program Manager at ONR in covering each of the separate three year periods, Refs. 1-3. where we summarize the achievements. These were: 1) letter report from Professor Tulin to Dr. Gene Silva, dated September 22, 1987; 2) letter report from Professor Tulin to Dr. Steve Ramberg, dated December 25, 1988 and 3) letter report from Prof. Tulin to Dr. Steve Ramberg, dated December 22, 1989.

Overview:

This contract has been the major research program within the Ocean Engineering Laboratory since its inception and has played a vital role in the growth of our educational and scientific research program in ocean engineering. With the help of this program we have been able to attract and train highly talented students and to carry out increasingly significant research in ocean engineering.

Our research has touched on a number of important subjects in the major fields of waves and dynamics, with an emphasis on non-linear aspects. At the end of the contract period (1989-90) our strongest direction was toward non-linear ocean waves, and especially ocean spectra and breaking.

During this period our laboratory has been put into operation and has grown continuously in capability through the research program. It is today a major asset for ocean engineering research at a high scientific level.

Research Subjects:

Research has been carried out under this contract on the following range of subjects: i) Wave Breaking (steady and unsteady); ii) Directional Sea Generation; iii) Wave Resonant Phenomena in Wave Tanks; iv) Deep Mooring; v) Internal Wave Generation by Ships, including Solitons; vi) Non-linear response in Seaways. At the end of the contract period, the work on deep mooring and on non-linear response had been successfully completed and had been replaced by vii) hydrodynamics and dynamics of fiber optic cables.

i) Wave Breaking:

- A successful model of steady state breaking was constructed and applied to the experimental data of Duncan, with excellent agreement. The model provides for the first time, a deep and fundamental understanding of steady state planar breaking.

- The steady state model has been extended to the case of unsteady breakers and the stability of breakers has been examined.

- Experiments have been conducted on the breaking of waves created by a hydrofoil under transient operation.

- Experiments have been carried out on the breaking of unsteady short crested waves, including measurements of breaking inception and the transient development of breakers. These are the first such measurements to have been carried out, and important information on transient breakers has been obtained in this way.

ii) Directional Wave Generation:

- A method has been developed for the simple generation of directional waves within the type of narrow tank widely used within ship and other hydrodynamic laboratories. This method involves the use of three-dimensional (shaped) wavemakers oscillating in heave.

- The basic theory for this wave generator has been developed including a simple (slender body) method for numerical waves prediction.

- Experiments have been carried out on a half-cone wavemaker in a wave flume showing excellent agreement with the theory in the linear wave regime.

- A shaped wavemaker has been installed in the large OEL wave tank and operated stochastically. A directional random sea following the Pierson-Moskowitz spectrum has been synthesized.

iii) Non-linear Wave Resonant Phenomena:

- Non-linear phenomena near the first tank resonance have been studied experimentally and theoretically, as they provide an excellent opportunity for the study of non-linear gravity waves.

- Systematic measurements have been made of non-linear (soliton-like) wave groups generated during near resonance operation. These showed, for the first time, the existence of a critical wavemaker amplitude, below which wave groups are not effectively generated, and the wave propagation is linear. We also discovered a linear relationship between the wave group propagation velocity and wavemaker amplitude theory.

- Existing non-linear theory has been applied and shown to be deficient (however, under the continuation of this contract, we have successfully developed new theory).

iv) Deep Mooring:

- An analysis has been made of the dynamics of platforms and cable systems for deep water mooring. The scaling of these dynamics has been especially studied.

- Based on these analyses, a method has been developed for the simulation of deep moorings in relatively shallow tanks, utilizing altered, but "equivalent", mooring systems and platforms.

- Model mooring systems have been constructed and their dynamics studied in our large wave tank.

v) Internal Waves Generated by Ships:

- The internal waves generated by ships have been studied both theoretically and experimentally.

- Theory was developed for the case of transonic operation, corresponding to Ekman's "deadwater" observed in rivers, fjords, and coastal regions. The very large wave drag due to internal wave generation was verified through computations using the theory. For the first time, the importance of upper layer currents was shown on the deadwater drag, explaining some very old and mysterious observations.

- Theory was begun for the case of supersonic (high Froude number) operation corresponding to modern ships in the ocean. This consists of two separate parts: a) far field theory leading to predictions of the wave patterns in terms of the stratification; b) near field theory leading to the prediction of the amplitude spectrum in terms of the ship's form and stratification.

- The development of a small towing tank and instrumentation was begun.

vi) Non-linear Motion Response:

- The important general problem has been studied of predicting resonant stochastic motions in a seaway, including the effect of quadratic damping. This problem is generally solved in engineering practice utilizing the approximation of equivalent linearization for the damping. Here a variety of powerful non-linear mathematical techniques have been utilized. The work has reached a very important conclusion: that equivalent linearization can provide accurate predictions, provided that a mathematically suitable method for finding the "equivalent" damping is used. A method for doing this was presented.

Facility Development:

The Ocean Engineering Laboratory has been continually upgraded during the contract period. Specific additions have included: A towing carriage for the flume; a hydraulic wavemaker for the flume; a small lightweight carriage for the large tank; wave measurement equipment for flume and the large tank. During the contract extension, concluding the contract, we completely rebuilt the computer driven hydraulic wavemaker on the large tank, resulting in a great improvement in its performance; we also carried out engineering studies for the modification of the tank to allow wind-wave studies.

Reporting and Publication:

It is our practice to write up all research work in the OEL on an ongoing basis; these are collected and stored as OEL Technical Reports. Some of these reports are actually technical papers presented at conferences (and usually published in Proceedings), and/or submitted for publication in referenced journals. A complete list of these reports is appended as Appendix A. There are a total of 30 reports during this period.

We consider it very important to take part in professional conferences, symposia, and specialist meetings. Many of these are by invitation, and in almost all of these, the papers are selected in advance. Participation in these meetings allows for rapid dissemination of research results, as well as for the opportunity for immediate feedback and prolonged discussion. We have a policy to encourage the attendance at these meetings of our graduate students, as it is extremely important for their professional development. During this contract period we have presented 10 papers at such meetings and have published them in Proceedings of these Conferences and/or professional journals.

Student Participation:

During this contract period we have supported fourteen graduate students. Four of these have received their Ph.Ds. Three are at this time completing their Ph.D. dissertations. Eleven MSs have been awarded.

Visitors and Other Participation:

The program has benefited from the participation of a variety of visitors, who spent prolonged periods in our Laboratory. These included: Professor Trygve Nilsen, Bergen University; Professor Hajime Maruo, Yokahoma University; Professor John Leonard, OSU; Professor X. Huang, Chou Tung University; Professor Touvia Miloh, Tel Aviv University; Dr. Ted Shugar, NCEL; Dr. Sigurd Falch, Trondheim Technical Institute.

Patents:

No patents were applied for.

Students supported (fully or partially) under Contract N00014-86-K-0866, 10/89-4/91.

STUDENT	MS	PHD	COMMENTS
R. Bozarth			no degree
R. Cointe	S 85	F 87	
C. Duthoit		F 87	
A. Koliani		M 88	
J. Leonard	S 84	M 88	
H. Ma	S 89		Ph.D. exp 1992
S. Neushall	F 88		
T. Ottenheimer	F 89		Pursuing a Ph.D. at OSU
H. Qu	F 89		
L. Pedersen	F 88		
V. Saubestre	F 84		
S. Welch	F 89		Ph.D. exp. 1992
S. Wolfe	S89		Ph.D. exp. 1992
D. Regis			MS exp. 1992
Y. Yao			Ph.D. exp. 1992

PUBLICATIONS FROM ONR SPONSORED WORK - FY 87/FY 89
MARSHALL P. TULIN

86-3-C "A Theory of Spilling Breakers," by M.P. Tulin & R. Cointe, 10/86.
Presented at the 16th Symposium on Naval Hydrodynamics, Berkeley, CA. 7/86. To appear in the Proceedings, National Academy Press, Washington, D.C.

86-7-C "Steep Short-Crested Waves Produced by a Simple Three Dimensional Wavemaker," by M.P. Tulin & A. Kolaini, 10/87.
Presented at the American Towing Tank Conference (ATTC), Washington, D.C., 8/87 and to appear in the Proceedings.

87-12-R "Nonlinear Response of Marine Vehicles to Stochastic Signals: A Review," by C. Duthoit, 2/87.

87-14-T "A Theory of Breakers and Breaking Waves," by R. Cointe, 8/87.
A doctoral thesis of 225 pages. Later to be published as a paper by M.P. Tulin and R. Cointe.

87-15-T "Nonlinear Stochastic Response of Marine Vehicles," by C. Duthoit, 8/87.
A doctoral thesis of 166 pages.

87-16-C "A Theory of Spilling Breakers," by M.P. Tulin and R. Cointe, 8/87.
Presented at the IUTAM Conference on Non-Linear Waves, Tokyo, 8/87.
To be published by Springer in the Proceedings.

87-17-P "Nonlinear Stochastic Response of Marine Vehicles," by J.L. Armand & C. Duthoit, 8/87.
Submitted for publication to Probabilistic Engineering Mechanics.

87-18-C,P "Nonlinear Dynamic Behavior of Moored Platforms Driven by Stochastic Seas," by J.L. Armand & C. Duthoit, 8/87.
Presented at the 6th OMAE Symposium, Houston, Texas, 1987.
Submitted for publication to the Journal of Offshore Mechanics

and Arctic Engineering.

87-19-C Breaking Waves at Sea: Modelling and Applications
Proceedings of the 1988 ASME-OMAE Houston Conference
by M.P. Tulin & R. Cointe

87-24-R A Review of Mooring Analysis and Experimentation
by John S. Leonard

88-25-C Turbulent Spilling Breakers at Sea
8th Symposium on Turbulence and Diffusion, American Meterological Society, San Diego
by Sigurd Falch, Stephen R. McLean, Marshall P. Tulin

88-28-R Surface Gravity Waves: Non-linear Behaviour in Theory, Experiment, and Nature
Synopsis of Workshop held at UCSB, May 31-June 1
Reported by Touvia Miloh & Marshall Tulin

88-29-P Long Interfacial Waves in a Two-Fluid System with Application to the 'Dead-Water' Phenomenon, J. Fluid. Mech. (in press)
by T. Miloh

88-30-P Periodic Solutions of the DABO Equation as Sum of Repeated Solitons
J. Phys. A: Math. Gen. 22 (1989) pp. 921-923
by T. Miloh & M.P. Tulin

88-31-R Dead Water Phenomena: A Non-linear Theory of Wave Disturbances Due to a Ship in a Shallow Thermocline
by T. Miloh & M.P. Tulin

88-32-R Transient Motion of Floating Bodies: Application to the Computation of the
Hydrodynamic Load Exerted on Ships in Collisions; A Review
by V. Saubestre

88-34-C Scaling Characteristics of Mooring Systems in Waves
Proceedings of the 8th OMAE Conference, The Hague, March 1989
by J. Leonard

88-35-P Radiation Stress and Surf Zone Modeling
by S. Wolfe

88-36-C A Theory of Dead Water Phenomena
Proceedings of the 17th Symposium on Naval Hydrodynamics, The Hague
by T. Miloh & M. P. Tulin

88-37-R	A Spilling Breaking Solitary Wave on a Sloping Beach by S. Falch & M.P. Tulin
88-38-R	Unsteady Spilling Breaking Waves by S. Falch and M.P. Tulin
88-40-R	Review of Analysis Methods for Directional Sea Spectra by H. Qu
89-41-C	Model Testing of Deep Water Mooring Systems Proceedings of the 22nd American Towing Tank Conference, St. John's Newfoundland, August 1989 by J. Leonard and M.P. Tulin
89-42-R	Time Series Plots of Mooring Experiments by J. Leonard
89-46-T (Ph.D. Thesis)	Experimental Characterization of Mooring Systems in Waves and an Introduction to Bi-Scaling by J. Leonard
89-47-T (Ph.D. Thesis)	Theoretical and Experimental Studies of Steep, Short-Crested Waves Produced by a Conical Wavemaker by A. Kolaini
89-48-R	Planar and Non-Planar Wavemakers and their Applications - A Survey by A. Kolaini